Visualizing the Evolution of HCI

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A study of the evolution of the HCI community is described based on information extracted from leading HCI journals. The study includes a traditional author co-citation analysis and a progressive domain visualization of a co-authorship network of 3,620 authors and a 1,038-node hybrid network of topical terms and cited articles. Emerging trends and prominent patterns of these networks are identified and compared with an existing survey of the field. The study contributes to the understanding of HCI at a macroscopic level as well as to the improvement of methodological implications.

Keywords: HCI and other communities, social network analysis, author co-citation analysis, co-citation networks.

1 Introduction

Human-Computer Interaction (HCI) is an interdisciplinary field. It takes years to educate and train an HCI expert and even longer to develop a thorough understanding of the subject matter as a whole and a visionary grasp of the past, present, and future of challenging issues and important directions. In many scientific fields, knowledge advances so fast that scientists must rely on comprehensive surveys and literature reviews to update their mental big picture of the field [Price 1965].

The literature of published articles in a field of study is a valuable resource for the scientific community. Scientists document and archive their work in their publications. Furthermore, scientists often make significant connections that may not previously have been conceivable, from connections within a field to connections across different disciplines. When scientists make references to earlier contributions, their behaviour can be seen as an endorsement of the significance of underlying issues. When a domain expert is preparing a subject matter review, the literature has an invaluable role to play. The expert would typically conduct thorough searches for relevant articles that were ever published on the subject. Then the expert would digest a large amount of articles; hundreds of articles would not be uncommon. The expert would augment her own view of the subject with details from these articles and develop themes that can tie the pieces together. Such surveys tend to cite more than 100 articles. The process is time consuming and subject to the biases of individual experts. By the time it is done, it may need substantial update. Finally, such surveys may not exist at all simply because no one commits to the daunting task.

Comprehensive surveys of scientific literature compiled by experts are indispensable to the growth of the scientific community. For example, such surveys tend to identify trends and make predictions. In this article, we describe an approach that is still being iteratively developed to facilitate both experts and novices to form a big picture of their field based on visual exploration of the literature.

The goal of our approach is to enable domain experts to quickly narrow down thousands of articles on a given subject to a small number of high-quality articles. These high-quality articles, along with emerging patterns of how they are perceived by fellow researchers in the field, are used to form a concise representation of the field. Our vision is that such approaches will largely simplify the time-consuming task of locating important articles in the literature. Furthermore, we expect that, because the automated process can be repeated easily, one would be able to take a snapshot of an evolving field more frequently. The big pictures produced by such an approach are expected to provide scientists and practitioners insights into how a scientific community communicates. The work has its own implications for HCI. The design of the visualization component and associated task analysis all pose new challenges to HCI.

The focus of this article is on the extent to which the approach can reveal significant structures and trends in the HCI literature. Five high-impact-factor HCI journals were identified as the input sources. All articles published in these journals were used to generate a co-authorship network and a hybrid network of topic terms and cited articles. The networks were visualized and analysed to identify interesting patterns and emergent trends. John Carroll's survey of HCI was used as our gold standard to interpret the resultant visualizations [Carroll 1997, 2001].

The rest of the article is organized as follows: first, we describe the method to be used; second, we describe the data and details of modelling and visualization;

third, we explain prominent structures, patterns, and trends found in the visualized networks; and fourth, we compare Carroll's survey with the resultant networks.

2 Methods

The study has three components:

1. A traditional author co-citation analysis.
2. A progressive knowledge domain visualization study.
3. A comparison with the comprehensive survey of the evolution of HCI [Carroll 1997, 2001].

2.1 A Traditional Author Co-citation Analysis (ACA)

We followed the standard bibliometric procedure described in White & McCain [1998]. We asked a group of HCI experts to identify the most relevant HCI journals from a list of candidate journals. The following 10 journals were chosen for the author co-citation analysis:

1. Behaviour & Information Technology.
2. Human–Computer Interaction.
3. IEEE Transaction on Systems, Man & Cybernetics.
4. International Journal of Man–Machine Studies.
5. Perception and Psychophysics.
6. Interacting with Computers.
7. User Modelling and User-adapted Interaction.
8. International Journal of Human–Computer Interaction.
9. Interfaces.
10. International Journal of Human–Computer Studies.

The 60 most-cited authors in the 10 journals were identified using the science citation database SciSearch. Next, the search was extended to all journals indexed in SciSearch to obtain the co-citation counts among the 60 authors. The 60 most-cited authors in the expanded search were used in the subsequent analysis. Traditionally, the number of authors is arbitrarily selected, although this process tends to become substantially time consuming with large numbers of authors. The search led to a 60-by-60 author co-citation matrix. A multidimensional scaling (MDS) solution was derived to represent the co-citation relationships between these authors.

Journal	Range	Articles
Human-Computer Interaction (HCI)	1994–2004	139
International Journal of Human-Computer Studies (IJHCS) — formerly International Journal of Man–Machine Studies (IJMMS)	1980–2004	1651
International Journal on Human-Computer Interaction (IJHCI)	1994–2004	232
Interacting with Computers (IwC)	1992–1999	254
	2002–2004	
User Modelling and User-Adapted Interaction (UM)	2001–2004	33
Total	1980–2004	2309

Table 1: Six HCI journals used in the knowledge domain visualization.

2.2 Progressive Knowledge Domain Visualization

The second part of the study is a progressive, knowledge-domain visualization of co-authorship relationships and article-term relationships [Chen 2004, in press]. Prominent patterns and emerging trends in a co-authorship network and a hybrid network of topical terms and cited articles were identified and discussed.

Six HCI journals of high impact factor were identified using the Journal Citation Report (JCR). Bibliographic records of articles in these journals were retrieved from the Web of Science (See Table 1).

The six HCI journals consisted of 2,309 articles. A co-authorship network was generated first. To qualify for the network, an author must have had at least one cited article in at least one year during the period between 1980 and 2004.

The second task was to generate a hybrid network that could represent emergent trends as well as prominent patterns concerning the big picture of HCI. The network was constructed based on fast-growing topical terms and co-cited articles. A subset of topical terms used in the titles, abstracts, and keyword lists of the 2,309 articles were selected by a burst detection algorithm [Kleinberg 2002], such that topical terms associated with a sharp increase in popularity were selected to represent emergent trends [Chen 2004, in press]. Articles cited by the 2,309 articles were selected if their citation counts exceeded citation thresholds varying across the 1980–2004 range. The entire range was divided into 25 time slices. Each time slice corresponded to one year. Since the general volume of the literature increases over time, an incremental threshold scheme was used, such that low threshold levels were used in the earlier time slices and high threshold levels were used in more recent time slices. Within each time slice, an associative network was constructed with two types of nodes: topical terms and cited articles. The two node types led to three link types:

1. Term-term.
2. Article-article.
3. Term-article.

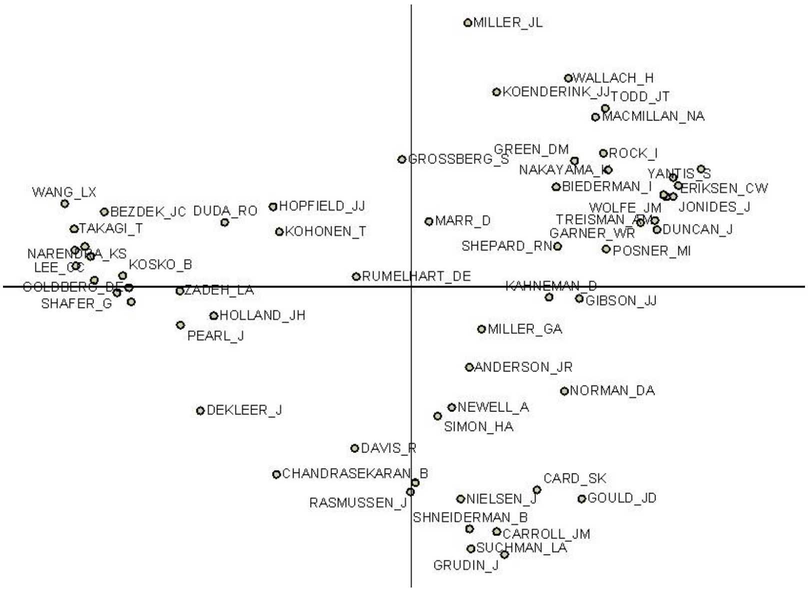

Figure 1: A multidimensional scaling solution of the 60 authors based on their co-citation relationships. Three clusters: left, upper right, and lower right.

The term-term links were between co-occurring terms, i.e. if two terms were found in the same article published in an HCI journal, for example, the term *website* and the term *evaluation* were found in the same article. The article-article links were between two articles that were cited together by articles in the five HCI journals. The term-article links were between a term *t* and an article *a*, such that the term *t* was in an article that cited article *a*. The time series of networks from all time slices were merged into a network that represents the entire period of time.

The resultant networks were visualized to reveal the citation and co-citation structure of the HCI literature. The entire procedure was automated [Chen in press]. Network visualizations were enhanced by highlighting high centrality nodes, which are regarded as playing salient roles in the global topological structure of a network. Emerging trends and prominent patterns in these networks were shown as timed links progressing from one time slice to another.

3 Results

3.1 Author Co-Citation Analysis

The multidimensional scaling (MDS) solution of the 60 authors' co-citation image suggests three groups of authors: the left, the upper right and the lower right ones (See Figure 1). The meaning of each grouping was identified by additional searches. A domain expert is expected to recognize a substantial number of the authors, whereas it could mean very little to a newcomer to a domain, which is one of the major inadequacies of the traditional ACA approach. The following interpretations were offered by three of the authors of this article, based on their own knowledge and additional searches.

Authors in the left half of the map are known for their work in Artificial Intelligence, especially fuzzy logic and fuzzy systems. Zadeh, just below the X axis, is best known for the idea of fuzziness. This group also includes names such as Kohonen, Duda, Pearl, and Shafer.

The upper right group includes Posner, near the X axis, Garner, Treisman, Duncan, Yantis. These names are usually associated with research on attention, visual attention, and visual search. Some were interested in neurograph, some in computer vision based on human cognitive models. Garner and Gibson, slightly below the X axis, were associated with writings on perception in the 1950s. On the X axis, near to Gibson, Kahneman was interested in decision making and uncertainty. Further to the south, there is Miller, the principle investigator of the WordNet project. Below Miller, Anderson was associated with cognition and learning. Gibson, Miller, Kahneman, and Anderson are prominent figures in cognitive psychology and cognitive science. Rumelhart, near to the origin in the upper left quadrant, is a founder of connectionism. It makes sense to see Kohonen nearby.

The lower right group includes Newell, Simon, Norman, Card, Nielsen, Gould, Shneiderman, Carroll, Suchman, and Grudin. Newell and Simon were famous for their work in artificial intelligence and fundamental cognitive science.

In summary, the MDS provides a loosely defined structure based on author co-citation profiles. Interpretations are primarily subjective because little information is directly available from the map. The following findings, produced by progressive knowledge-domain visualization, provide explicit and additional information concerning the time and nature of various groupings. The findings were obtained from a substantially larger sample of articles.

3.2 Co-authorship Network

A co-authorship network of 3,620 authors was generated for the period of 1980–2004. An author must be cited at least once in any of the time slices to be included in the network. The network contains a total of 5,401 co-authorship links. All links were preserved in the visualization of the network.

The 3,620-author co-authorship network can be seen as a social network. The largest component of a network and the longest path in such networks tend to reveal some interesting insights into the underlying phenomenon. The largest component of the 3,620-author network contains slightly more than 400 authors, which is more than 10% of the size of the entire network. The largest component consists of two branches and a dense cluster of 120 authors. One of the branches forms the longest path. A visualization of the co-authorship network is shown in Figure 2. The size of a circle denotes the number of articles that a given author published in the 5 HCI journals. The colour of a link shows the first time the two connected authors published an article together. The colours of an author show the number of articles the author published over time. The time-coloured rings progress inside out.

The largest co-authorship chain is highlighted in Figure 3. The path starts with Sutcliffe_A from the left and ends with the dense cluster of authors in the

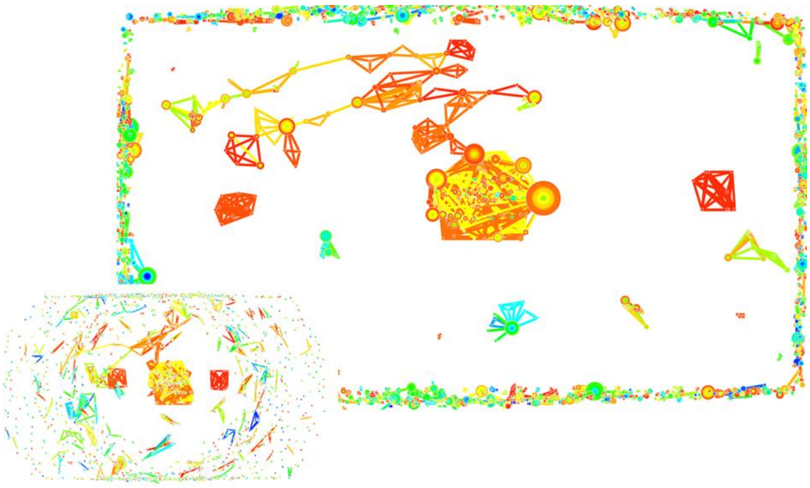

Figure 2: The co-authorship network of 3,620 authors, including 5,401 co-authorship links (1980–2004). The image at the lower left corner shows the snapshot of an earlier stage of the layout process. The finalized layout is shown in the larger image. The largest component of the network is essentially in the upper left quadrant. The dense cluster of 120 authors is located in the centre.

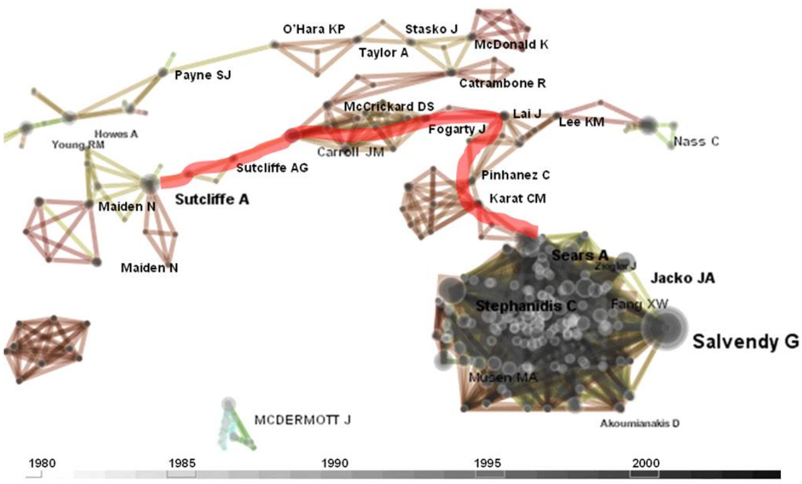

Figure 3: The largest component contains approximately 400 authors among the total of 3,620 authors. Salvendy, Stephanidis, and Jacko are prominent members of the 120-author cluster.

lower middle. There are a number of small clusters along the path. The following discussions will focus on the key points on the main path. Starting with Sutcliffe, the path includes Carroll, Fogarty, Lai, Pinhanez, Karat, and Sears as its key elements. The path is connected to the dense cluster via Sears. Within the dense cluster, Salvendy, Stephanidis, and Jacko are prominent cluster members in terms the size of their nodes. Some name labels in the image were added by hand for improved readability. The software, called *CiteSpace*[1], also produced visualization images in full colour.

To illustrate the type of information one can find from such visualizations, we traverse the path from Sutcliffe to Sears and to the 120-author cluster. For each co-authorship link on the main path, we located articles in the dataset as evidence. Authors off the main path will not be discussed in this article.

The first co-authorship link between Sutcliffe_AG and Carroll_JM was due to a 1999 article in IJHCS [Sutcliffe & Carroll 1999]. Sutcliffe_AG was in City University, England and Carroll_JM was in Virginia Tech, USA. The article describes reusable claims as a repository of HCI knowledge.

Carroll_JM and Fogarty_J are linked in the map because of a 2001 article in IJHCS on MOOsburg [Carroll et al. 2001]. All the authors were with Virginia Tech. The co-authorship link between Fogarty_J and Lai_J was because of a 2004 article in IJHCS [Fogarty et al. 2004]. Instead of Virginia Tech, Fogarty's more recent affiliation became Carnegie Mellon University. Lai_J's affiliation on this article was also Carnegie Mellon University. It is interesting to note that the third author was from IBM TJ Watson Research Center. The co-authorship link between Lai_J and Pinhanez_C led to a 2002 article [Lai et al. 2002]. Lai's affiliation on this article was IBM TJ Watson Research Center.

Pinhanez_C and Karat_CM are connected by a 2002 IJHCS article [Karat et al. 2002]; IBM TJ Watson was their affiliation. The connection between Karat_CM and Sears_A was established by a 2003 article in HCI [Sears et al. 2003].

Sears_A belongs to the dense cluster of authors. An interesting question would be what brings these authors together? In this article, we address some simple questions. Who are the prominent authors in this cluster? What articles did they co-author in the dataset? Does the cluster imply an emergent trend or even a paradigm shift in HCI?

A 20-author IJHCI article [Jacko et al. 2002], including Stephanidis_C, Salvendy_G, and Sears_A, in part explains the multiple connections. Stephanidis_C introduced the concept of 'User Interfaces for All' in 1995. Salvendy_G is the founding editor of the *International Journal on Human-Computer Interaction and Human Factors and Ergonomics in Manufacturing*. He is also a member of the National Academy of Engineering.

Does the dense cluster correspond to an emergent trend? Given the research interests of its prominent members, such as Salvendy_G and Stephanidis_C, we conjecture that the cluster might be related to *ubiquitous computing or user interfaces for all*. To verify this conjecture, we examine a hybrid network of cited articles and abruptly rising topical terms. We expect to find the presence of *ubiquitous computing or user interfaces for all* in the hybrid network.

[1]CiteSpace is available at http://cluster.cis.drexel.edu/~cchen/citespace

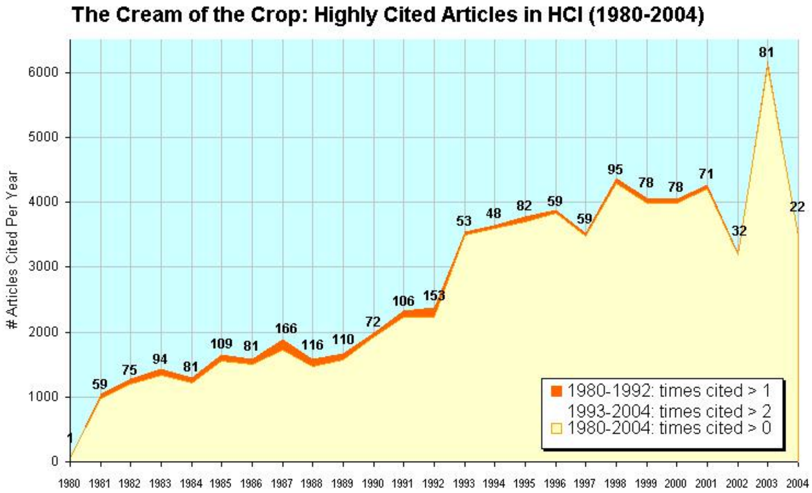

Figure 4: A total of 1,038 unique articles at the top layer are featured in the visualization, including 2,759 associative links.

3.3 Emerging Trends and Prominent Patterns

A 1,038-node hybrid network of topical terms and cited articles was visualized (See Figure 4 and Figure 5). The network contains two types of nodes: terms and articles. A link between a term and an article indicates that the term was found to be cited in the article. A link between two articles denotes a co-citation link; in other words, the two articles were cited together by other articles.

The process was configured as follows. The 25-year time span was divided into 25 time slices from 1980 through 2004. Three sets of thresholds were chosen for the first, the middle, and the last slices; and threshold levels for the remaining slices were obtained by linear interpolation. The three sets of thresholds were (2, 2, 20), (3, 2, 30), and (3, 3, 40), where the first number in a group is a citation threshold level, the second number is a co-citation threshold, and the third is a co-citation coefficient. For example, if (2, 2, 20) is assigned to a slice, it means that within the slice, an article needs to be cited at least twice, co-cited with at least two other articles, and its normalized co-citation coefficient is 0.20 or greater. It took 25 seconds to produce the visualization of the network of 1,038 nodes and 2,759 links.

Figure 5 shows a grey-scale version of the visualization. The legend bar on the top of the figure shows the time-coded grey-scale levels from 1980 through 2004. Therefore, lighter lines in the image were made earlier than darker lines. Similarly, lighter rings denote earlier citations than darker rings. In other words, recent patterns and emerging trends should be represented by darker shades.

Three types of information in the image are of particular interest:

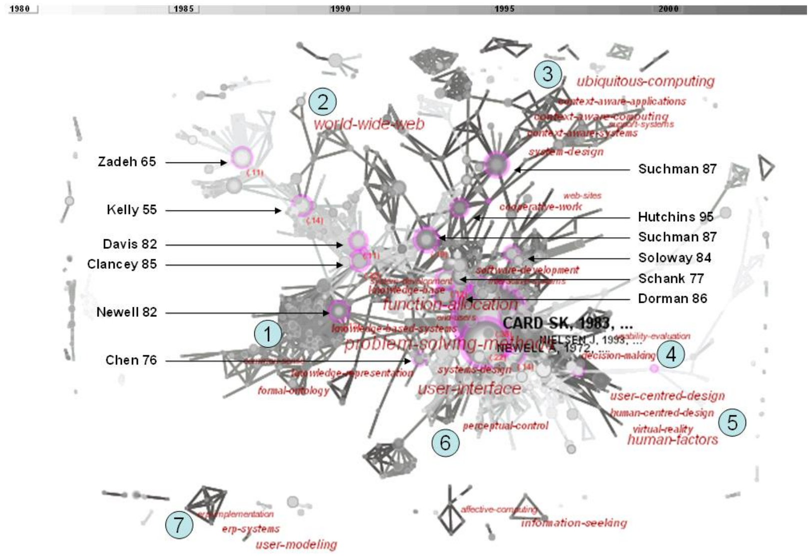

Figure 5: Seven areas of interest in a hybrid term-and-article network (Nodes = 1,038, Links = 2,759). Hubs are shown with purple rings, including three most prominent articles at the centre, Card et al. [1983], Newell & Simon [1972], and Nielsen [1993].

1. Topical terms.
2. Hub articles.
3. Areas.

Some of the topical terms are shown in Figure 5. Given that all selected topical terms demonstrated sharp increases in their popularity, they can be seen as tokens of emerging trends. Because they are directly connected to the cited articles in the network, topical terms provide direct evidence for us to interpret the nature of a link and even that of a cluster.

Hub articles were those with high centrality. They are shown as a circle with an extra purple ring and a label such as (0.14), which is the value of its centrality. Fifteen such articles are marked in the figure. For example, [Zadeh 1965] denotes a 1965 article by Zadeh. The citations of the articles and their centrality are summarized in Table 2.

The third type of information is areas identified by circled numbers (1–7) in the Figure. These numbers identify areas of a trend in the past or an emerging trend. The nature of such an area can be characterized by corresponding topical terms and hub articles.

Seven areas of interest are marked in Figure 5. Each area is identified in connection with a number of topical terms and prominent articles. The seven areas are:

# Citation	Centrality	Author	Year
144	0.38	Card SK	1983
91	0.22	Newell A	1972
72	0.02	Nielsen J	1993
44	0.06	Suchman L	1987
40	0.19	Suchman LA	1987
40	0.07	Norman DA	1986
35	0.11	Zadeh LA	1965
34	0.12	Newell A	1982
33	0.14	Kelly GA	1955
33	0.12	Schank RC	1977
31	0.22	Clancey WJ	1985
30	0.09	Hutchins E	1995
28	0.11	Davis R	1982
25	0.05	Soloway E	1984
22	0.06	Chen PPS	1976

Table 2: The 15 marked hub articles in the hybrid network.

1. Knowledge representation and problem solving methods.
2. The World Wide Web.
3. Ubiquitous computing and context-aware computing.
4. Usability evaluation.
5. User-centred design.
6. Perceptual control.
7. Enterprise resource planning.

The core of HCI, at the centre of the network, is featured by three overwhelmingly prominent articles: Card et al. [1983], Newell & Simon [1972], and Nielsen [1993]. The citations to these three were so high that we did not attempt to specify the nature of such references. We conjecture instead that the three masterpieces formed the cornerstones of HCI. By examining other emerging trends, we expect to improve our understanding of the roots of HCI.

1. Knowledge representation and problem solving methods. The hub article in this area includes [Newell 1982], [Clancey 1985], and [Davis & Lenat 1982]. Moving upwards, we found a branch stretching to the upper left corner, containing [Zadeh 1965], and [Kelly 1955].

2. The World Wide Web. The topical word world-wide-web in this area points to [Bush 1945] and [Berners-Lee et al. 1994]. Earlier hypertext articles are also concentrated in this area, including [Conklin 1987] and [Halasz 1988].

3. Ubiquitous computing and context aware computing. This area is highlighted by terms such as ubiquitous-computing, context-aware-systems, context-aware-computing, and context-aware-applications. This area includes [Dey et al. 2001] and [Dourish 2001]. This area appears to be rooted in the main HCI continent via a hub article [Suchman 1987]. There is another entry for the same book, nearer to the centre of the structure. The connection between situated actions and context aware computing appears to be evident. [Hutchins 1995] is another hub article, which should be also important to ubiquitous computing. An earlier footprint in the adjacent area was made by group support systems. A lighter grey area is partially covered by the context-aware-systems term. Its colour is lighter than the ubiquitous computing area, suggesting that it was an earlier trend in the evolution of HCI. Articles here include [Short et al. 1976], [Bly et al. 1993], [Keisler et al. 1984], and [Nunamaker et al. 1991].

4. Usability evaluation. [Cohen 1960] and [Nielsen & Mack 1994] are the highly cited members of this area. The area is connected to the core of HCI via [Gray & Salzman 1998], which turns out to be a review of experiments that compare usability evaluation methods.

5. User centred design. This area is characterized by terms such as user-cantered-design, human-centred-design, human-factors, and virtual-reality. Articles in this area include [Card et al. 1978], [Shneiderman 1998], [Cuff 1980], [Gaines 1981], and a 1992 edition of Shneiderman's *Designing User Interfaces*. [Gaines 1981] also has a centrality of 0.08. An interesting observation is the frequent British spelling of the word 'centred', which suggests that there was a trend of articles being published by British HCI researchers.

6. Perceptual control. This is a relatively small area compared with the others. It is interesting because it is connected to the primarily light grey area of the core HCI. Cited articles in this area include [Powers 1978] and [Engel & Haakma 1993]. [Taylor 1988] appears to be a main connection between this area and the core HCI; the article was about layered protocols for computer-human dialogue.

7. Enterprise resource planning. This area is currently isolated from the largest component of the HCI network. [Davenport 1998] and [Sumner 1999] are included in this area.

The hybrid network reveals a rich body of information concerning the evolution of HCI. Ubiquitous computing, rooted in situated actions and context aware computing, is indeed shown as an emerging trend, which echoes the dense cluster of 120 highly collaborating HCI authors we found in the co-authorship network of HCI. The findings of the three networks, namely a traditional author co-citation network of 60 authors, a co-authorship network of 3,620 authors, and a hybrid network of 1,038 topical terms and cited articles, are discussed with reference to a leading HCI expert's account of the evolution of HCI [Carroll 1997].

4 Discussions

Carroll identified four roots of HCI [Carroll 2001] and suggested that the evolution of HCI can be seen as being driven by a grand challenge of bringing them together. The four roots were identified as follows:

1. Prototyping and iterative development from software engineering.
2. Software psychology and human factors of computing systems.
3. User interface software from computer graphics.
4. Models, theories, and frameworks from cognitive science.

To verify and evaluate the viability of our methods, we need to address the extent to which one can identify the four roots in the visualizations of the HCI literature. The present study only used a limited part of the HCI literature, namely only from 10 journals in author co-citation analysis and 5 journals in the second part of the study. Publications in the ACM SIGCHI conference series are currently not included. We are planning to expand the coverage of the data in further studies in the near future. In the following discussions, we should bear this limitation in mind. On the other hand, the data we used in this study ranges from 1980 through 2004, whereas Carroll's review was published in 1997 [Carroll 1997] and updated in 2001 [Carroll 2001]; we expect that we may see some emerging trends that were not covered in the 2001 update. [Carroll 1997] cited 136 references, 43 of which were also found in the hybrid network in this study. The mean of citations across the 1,038-node network is 7.96 (standard deviation of 8.75). In contrast, the mean of citations of articles in both the network and Carroll's reference list is 20.7 (standard deviation of 25.4). At least for the topics common to both Carroll's review and our network, articles picked by Carroll tend to have 2 or 3 times more citations. This interesting finding shows the indispensable value of comprehensive surveys conducted by leading experts.

The Carroll review identified that user-centred system development was a framework that was intended to integrate the two foci of methods and software in the broader context of the first root. In earlier sections, we identified user-centred design as one of the seven areas in the hybrid network.

The closest connection was found with the 4th root — Models, Theories, and Frameworks. The prominent example given by Carroll in his review is the GOMS model for analysing routine human-computer interactions. Carroll cited [Card et al. 1983], which is shown as the most highly cited article in the hybrid network. With reference to Carroll's review, the core HCI identified in our visualization appears to be the foundations of HCI in terms of models, theories, and frameworks.

The trend of universal access is relatively easy to notice because of the prominent dense cluster in the co-authorship network. The unusually large number of co-authoring clusters tends to be a sign of a large movement involving many people. Co-authorship network visualization, especially analysing the largest component and the longest paths, appears to be an effective and interesting way to learn the structure of invisible colleges in a field. The two articles, [Stephanidis et al. 1998] and [Stephanidis et al. 1999], can be identified as the white papers of the universal access movement.

The primary strength of this approach is the provision of a tool that enables a wide variety of users to explore the dynamics of their domain literature. The tool can largely reduce the complexity of literature survey tasks by identifying potentially important articles from a vast body of publications. The tool also provides researchers with an alternative perspective so that they can cross reference issues identified in literature surveys conducted in traditional methods and those identified in the knowledge-domain visualization approach.

This approach is quantitative in nature. It has limitations and weaknesses. For example, what is visualized is determined by what input is provided to the system. To an extent, the views of domain experts are already reflected in the visualized patterns because they represent an abstraction of the latent, collective, and accumulative citing patterns. On the other hand, the selection of journals based on journal citation impact ratings may lead to a visualization that could considerably differ from a visualization based on a different source, for example, articles published in HCI conference proceedings as we mentioned earlier. As one reviewer pointed out, long-term interests in the literature may not be sufficiently reflected in the visualizations because of the emphasis on burst terms, although long-term interests could be represented by clusters of cited articles.

Domain analysis typically raises issues beyond the knowledge domain *per se*. One researcher may be particularly pleased and willing to accept the validity of a given visualization because his/her work is prominently featured. In contrast, one may be reluctant to do so if the visualization is considerably different from his/her mental model. Users should bear these factors in mind when using such visualizations. We recommend a hybrid methodology that combines quantitative and qualitative perspectives [Hjorland & Albrechtsen 1995].

5 Conclusions

In conclusion, the study has enabled us to compare the big pictures of HCI as it is delineated by different methods. Co-authorship networks and hybrid networks of topical terms and co-cited articles are a valuable tool for both experienced domain experts and relatively inexperienced newcomers. For domain experts, the tool can reduce the burden of locating various potentially relevant articles and help select high quality publications from the much larger pool of published articles. Because the method is much less expensive compared to a conventional expert review, it can be operated repeatedly and periodically. For newcomers to a field, the method can provide a guided tour of the landmarks of a field.

In terms of future work, it would be valuable to compile a comprehensive dataset of the HCI literature. Our next goal is to investigate quantitative approaches to the identification of patterns and emerging trends that may not yet form a prominent profile. This is a significant technical challenge as we acknowledge the fact that visualizations generated by the current method tend to be overwhelmed by a few high-profile articles, whereas low-profile ones tend to be underrepresented or undetected. A potential contribution to the field of HCI as a whole is to improve the understanding and recognition of HCI to a wider public and to people who know little about the field of HCI.

HCI is such an interdisciplinary, ubiquitous, and evolving field that it is vital to maintain a big picture of its growth. The examples, as shown in this study, invite new perspectives of HCI so that one can develop more usable and useful tools.

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